UNIVERSITY OF CALIFORNIA, SAN DIEGO (UCSD)

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO   SANTA BARBARA • SANTA CRUZ

CENTER FOR ASTROPHYSICS AND SPACE SCIENCES (CASS)

9500 GILMAN DRIVE #0424
LA JOLLA, CALIFORNIA,
92093-0424

31 December 2009

Lt. Jack Shepherd
Assistant Program Manager, Physics and Electronics Directorate
Air Force Office of Scientific Research
Arlington, VA 22203-1768
Phone: (703) 696-5994
Fax: (202) 767-4986

Dear Lt. Shepherd,

Attached find copies of our final report for award **FA9550-06-1-0107** for "A Study of the 3-D Reconstruction of Heliospheric Vector Magnetic Fields from Faraday-Rotation Inversion" for work performed from 2005 – 2009 by the University of California at San Diego.

There are three aspects to this research: 1) The inversion of simple synthetic Faraday-rotation measurements that can be used to demonstrate the feasibility of performing this inversion when and if Faraday-rotation observations become available. 2) The inversion of modeled heliospheric density and magnetic field data to provide these same results for complex structures. 3) The use of a 3-D MHD kernel in a time-dependent heliospheric tomographic inversion technique in order to demonstrate that the 3-D MHD model can be iteratively inverted to provide not only 3-component magnetic fields, but also other heliospheric solar wind parameters that incorporate these magnetic fields, as well as solar wind density and velocity.

We made progress on all aspects of this research, and have added a new forecast aspect in lieu of not having data with which to attempt the inversions of Faraday rotation from the Murchison Widefield Array (MWA) or other low-frequency radio system. There are 36 journal articles, and over 80 conference proceedings abstracts associated with this contract.

Sincerely yours,

Bernard V. Jackson

Bernard V. Jackson

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
11-30-2009

2. REPORT TYPE
Final Report

3. DATES COVERED *(From - To)*
03-01-06 to 08-31-09

4. TITLE AND SUBTITLE
A Study of the 3-D Reconstruction of Heliospheric Vector Magnetic Fields From Faraday-Rotation Inversion

5a. CONTRACT NUMBER
FA9550-06-1-0107

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Bernard V. Jackson, A. Buffington, P. Paul Hick, Mario M. Bisi

5d. PROJECT NUMBER

5e. TASK NUMBER
RD

5f. WORK UNIT NUMBER
UC

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

The Regents of the University of California, San Diego
9500 Gilman Drive
La Jolla, CA 92093

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
The Air Force Office of Scientific Research
USAF AFMC AFOSR/RSE
Arlington, Virginia 22203-1768
Contract Manager: Kent Miller

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFOSR

12. DISTRIBUTION / AVAILABILITY STATEMENT

Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

One of the most-sought heliospheric parameters is the vector (three-component) magnetic field. The magnitude and direction of magnetic field is of interest scientifically as parameters that characterize the heliosphere and relate outward-flowing solar wind plasma to the density and velocity structures that provide its transport. Moreover, it is this field that interacts with other objects imbedded in the interplanetary medium. For the Air Force, these interactions are of primary interest at Earth where a southward interplanetary magnetic field (Bz negative) can couple with the Earth's magnetic field at the boundary of the magnetosphere, causing geomagnetic storms. In addition, solar energetic particles (SEPs) which account for some of the most damaging radiation hazards to high-flying aircraft and astronauts are confined to magnetic fields that connect Sun with Earth.

At UCSD we have provided an inversion mechanism that can remotely determine heliospheric vector magnetic fields, their strength, and location in 3-D, and provided a mechanism to image these. We have also shown how these can be modeled, extrapolated, and refined in 3-D using MHD simulations. In addition we have developed an extension to the UCSD 3-D inversion technique that allows far more accurate forecasts of these vector fields prior to their Earth-arrival.

15. SUBJECT TERMS
Sun-Earth Connection Forecasts - Coronal mass ejections - heliospheric plasma – 3-D tomography – Ground-based radio and Spaceborne optical instruments

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Bernard V. Jackson
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	UL	23	**19b. TELEPHONE NUMBER** *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED			(703) 696-5994

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

Contents

FIGURES

A Study of the 3-D Reconstruction of Heliospheric Vector Magnetic Fields from Faraday-Rotation Inversion

(Final Report for AOFSR award FA9550-06-1-0107)

Objectives:

One of the most-sought heliospheric parameters is the vector (three-component) magnetic field. The magnitude and direction of magnetic field is of interest scientifically as parameters that characterize the heliosphere and relate outward-flowing solar wind plasma to the density and velocity structures that provide its transport. Moreover, it is this field that interacts with other objects imbedded in the interplanetary medium. For the Air Force, these interactions are of primary interest at Earth where a southward interplanetary magnetic field (Bz negative) can couple with the Earth's magnetic field at the boundary of the magnetosphere, causing geomagnetic storms. In addition, solar energetic particles (SEPs) which account for some of the most damaging radiation hazards to high-flying aircraft and astronauts are confined to the magnetic fields that connect Sun with Earth.

Current analyses rely on the extrapolation of magnetic field from the solar surface upward through the interplanetary medium. These solar surface extrapolations have one great difficulty: they do not show the major coronal changes in magnetic field responsible for Coronal Mass Ejections (CMEs) that have the greatest effect on the Earth's magnetosphere, and that produce the most damaging SEPs. While many attempts have been made to characterize the eruption of CMEs and CME energetics, the major CME energy release is presumed to take place in the solar corona. As yet these changes that take place above the solar surface have not been observed directly. Here we have proposed to study a method which would directly observe vector magnetic fields as they move outward from the Sun into the interplanetary medium and to determine their strengths and direction.

There are three aspects to this research: 1) The inversion of simple synthetic Faraday-rotation (FR) measurements that can be used to demonstrate the feasibility of performing this inversion when and if FR observations become available. 2) The inversion of modeled heliospheric density and magnetic field data to provide these same results for complex structures. 3) The use of a 3-D MHD kernel in a time-dependent heliospheric tomographic inversion technique in order to demonstrate that the 3-D MHD model can be iteratively inverted to provide not only 3-component magnetic fields, but also other heliospheric solar wind parameters that incorporate these magnetic fields, as well as solar wind density and velocity.

Final Status:

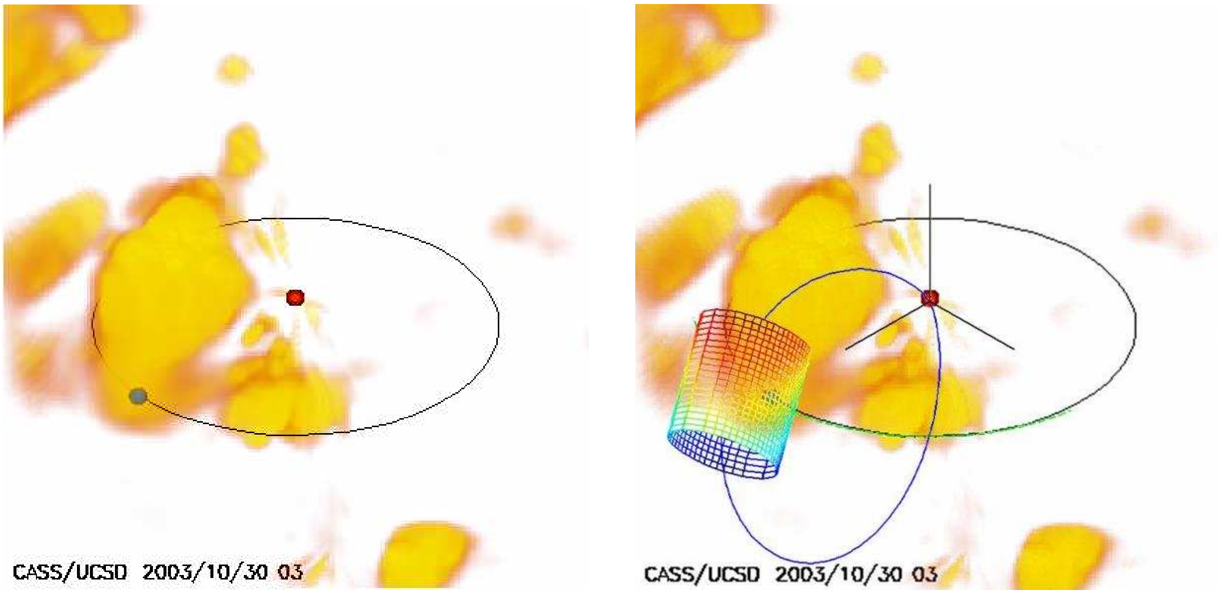
During this contract we used both kinematic and MHD solar wind models to provide inputs to the 3-D reconstruction process, and we tested the 3-D FR inversion process we developed using realistic test inputs. We also provided a standardized data format for the IPS data proxy to be used to determine density from IPS arrays. This standardized IPS data format will allow different radio arrays to provide similar density measurements that can be used to reconstruct the FR results used to map densities to spacecraft *in-situ* measurements. In addition, we invented an extension to the UCSD inversion technique to incorporate *in-situ* measurements into the tomographic analyses. This inversion, a combination of remote sensing and *in-situ* measurements, allows far more accurate data forecasts from already-measured values, and can be extended to vector magnetic fields using FR.

A Study of the 3-D Reconstruction of Heliospheric Vector Magnetic Fields from Faraday-Rotation Inversion
(Final Report for AOFSR award FA9550-06-1-0107)

For this contract we programmed, refined and tested a Faraday-rotation (FR) inversion analysis that allows a measurement of 3-component heliospheric magnetic fields using our time-dependent computer analysis. This included inputs of realistic magnetic field signals and the application of UCSD-based imaging to display these results (Jensen *et al*., 2006; 2009). The analysis works in our tomographic technique by changing the rotation variable from a positive–negative value by expansion in a Taylor series and then changing back after the inversion is performed (Jackson *et al*., 2008b). This promises a means to map the vector component of the magnetic field in and around coronal mass ejections (CMEs) and other heliospheric transient magnetic structures if the FR and electron density of the media can be learned accurately-enough. This software development is intended to be combined with radio FR observations when they are measured. To this end we have also explored observations of electron density proxies as well as our inversion technique prior to obtaining FR data from ground-based radio arrays.

The Murchison Widefield Array (MWA) partially funded by the National Science Foundation and the Air Force, and sited in Western Australia is one of the primary possibilities for testing this inversion technique with real data. The radio array now under construction is planned as a frequency-agile low-frequency array that has space weather as one element of its scientific goals. In December of this year, the initial 32-element MWA antenna system has shown that it can obtain signals from bright radio sources. For measurement of FR from this system we expect a larger number of antenna elements to be deployed (512 elements were proposed for the original low-frequency demonstration). If FR signals from this system are simultaneous with Solar Mass Ejection Imager (SMEI) currently in operation, and/or interplanetary scintillation (IPS) data, we will combine them in a scientific investigation to determine the extent to which they answer questions about CME density, velocity, and *magnetic field* structure. Slow progress in providing polarized measurements from the MWA has caused us to re-think the potential analysis to be done in the immediate future with this system, and we have also begun courting these same analyses using the European-based LOw Frequency Array (LOFAR) system. LOFAR is not at an optimal site for solar observations. However, the LOFAR system can certainly be used to ascertain the validity of the UCSD inversion algorithm using real data, as long as data from LOFAR can be made available. Partially to this end, the NSF and UCSD helped sponsor the Aberystwyth Remote-Sensing Workshop convened in May 2009 allowing LOFAR representatives the opportunity to view progress in the display, measurement, and forecast of heliospheric data using these algorithms and imaging techniques. This has resulted in a special issue of *Solar Physics* highlighting these efforts.

Currently, magnetic field magnitudes and direction in the heliosphere are mapped upward from the surface of the Sun using techniques that do not allow measurement of coronal magnetic field change. It is this change and these magnetic fields that are most responsible for the large changes in the Earth’s magnetic field during the passage of CMEs near Earth. Large, organized loop-shaped magnetic field structures associated with CMEs can sometimes be observed, and these reconstructed by *in-situ* techniques after Earth passage. Figure 1 shows one of these events during the 2003 Halloween-storm CME events (see Jackson *et al*., 2006). This is one of the events we have chosen to test our FR inversion analyses, and that was used to provide realistic inputs to UCSD imaging algorithms (Jensen *et al*., 2006, 2009). In the Jensen *et al*. (2009) simulation of FR using this event,



(a) **(b)**

Figure 1. **(a)** Solar Mass Ejection Imager (SMEI) 3D density reconstruction of the heliospheric response to the 28 October 2003 CME viewed from 3 AU 30º above the ecliptic plane and 45º west of the Sun-Earth line. The Earth is indicated as a blue circle in its elliptical orbit. The Sun is indicated by a red circle. Contours are from 10 $e^{-}cm^{-3}$ to 30 $e^{-}cm^{-3}$ and have an r^{-2} density gradient removed. A portion of the ejecta associated with a solar prominence is observed to the south of the Sun in this view from Jackson *et al*. (2006). The density structure of the CME populates the inner core of the giant magnetic loop for this event. These are the best available *realistic* CME 3D density reconstructions (*and not simulations*) available to date. **(b)** Same as (a) with reconstructed flux rope cylinder from ACE superposed (as in Jensen *et al*., 2006; 2009).

a simulated uniform shock sheath addition to the analysis was added to the CME plus extrapolated solar surface magnetic fields (Dunn *et al*., 2005) to provide inputs of this type CME feature to the FR analysis. The shock sheath is not shown in the low-resolution (Figure 1) 3-D reconstructions of this event, but has been reconstructed in more recent higher-resolution 3-D analyses of SMEI inversions as a density enhancement to the west of the Sun-Earth line (Figure 2). These analyses show an interesting and challenging aspect for heliospheric shock sheaths - that they are not a uniform front ahead of a driver (such as a CME), but that they generally form a piecemeal density front moving outward into interplanetary space. This is noted in articles and recent presentations partially sponsored by this research (Jackson *et al*., 2009b,e).

FR observations Φ measure both density and magnetic field along the line of sight: these are an integral combination of magnetic field strength and density,

$$\phi \propto \lambda^2 \int n_e \vec{B} \bullet \vec{dS} \qquad (1)$$

where λ is the wavelength, n_e is the electron density along the line-of-sight interval dS, and B is the magnetic field vector. A FR simulation of the same 2003 Halloween-storm CME event during passage by Earth of the large organized loop is shown in Figure 3.

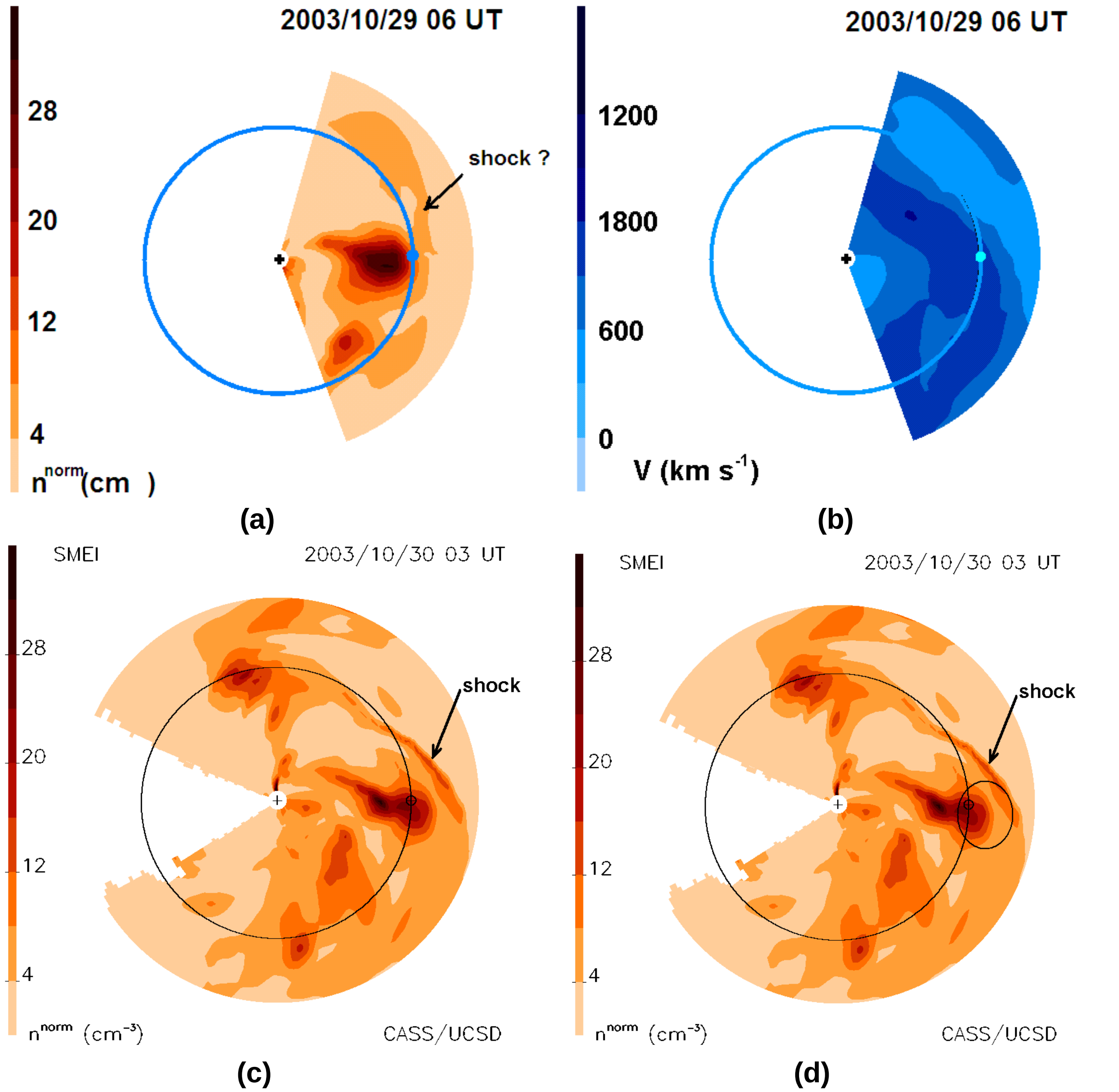
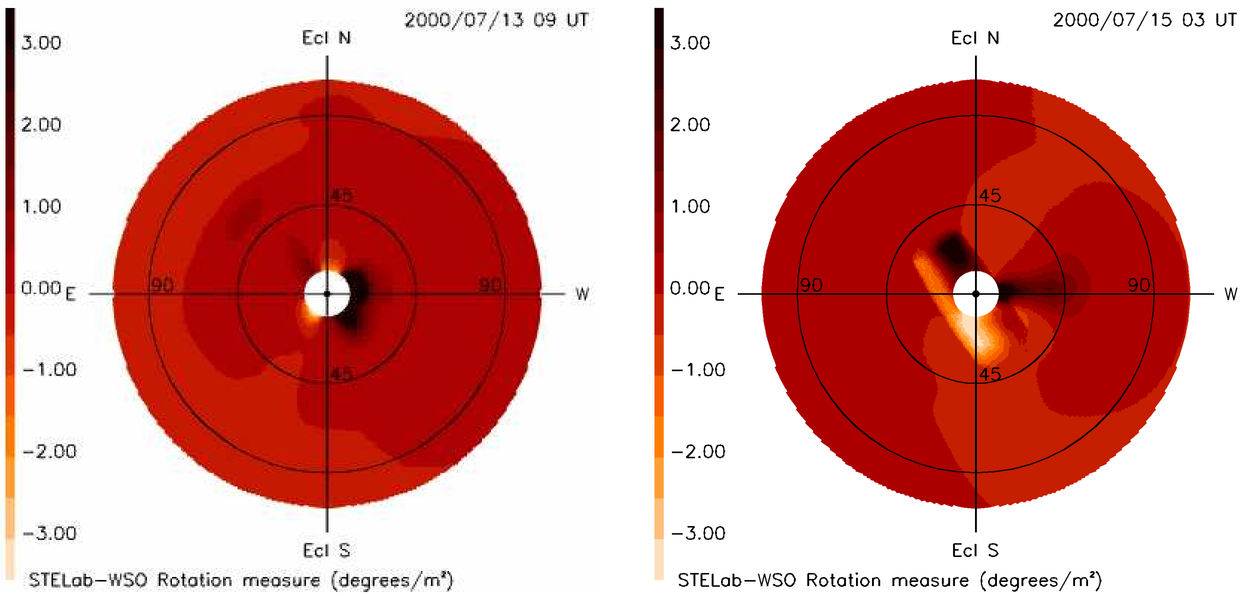


Figure 2. Ecliptic plane cuts of the 28 October 2003 CME at the time indicated. **(a)** Low-resolution SMEI 3-D density reconstruction of the 28 May halo CME as it reaches Earth as in Figure 1a. Earth is to the left of the image as a blue dot, and the density scale is given to the left of this presentation. The main structure that has just to arrived at Earth is associated with the halo CME observed by LASCO on 27 October 2003. In front and to the flanks of this dense material, a density enhancement that has the manifestations of a shock from the CME can be observed in theanalysis. **(b)** Low resolution STELab 3-D velocity reconstruction at the same time showing the general extent of the high speed solar wind region that follows the shock into the heliosphere. **(c)** The newer higher-resolution reconstruction ecliptic cuts of this event available since spring 2008 (for a slightly later time – the same time as presented in Figure 1). **(d)** The location of the reconstructed flux rope for this CME event superimposed onto density analysis.

As a heliospheric structure passes Earth, we expect the perspective views provided by the passage of a structure to allow resolving the degeneracy of where each structure lies along the line of sight. We currently provide a similar reconstruction of line-of-sight velocity and density from IPS observations in real time (see **http://ips.ucsd.edu/**), and from SMEI white-light observations (see



(a) **(b)**

Figure 3. **(a)** Rotation Measure (RM) shown for with background magnetic field extrapolated from the solar surface to provide the FR signal (from the densities reconstructed during the Bastille Day CME). **(b)** The same density but with the magnetic loop as observed in ACE for this CME added to the IPS 3D reconstructed velocity to provide a sky map of Faraday rotation. The minimum signal from the MWA (expected to be a few degrees at 100MHz or ~3m) should be adequate to reconstruct this loop using the signals obtained from these RM measurements provided there are enough lines of sight covering the sky throughout the period of observation. The density loop and the magnetic loop (2 giant heliospheric loops systems) derived from these two very different 3D reconstruction techniques are not superimposed for this FR result.

http://smei.ucsd.edu/). The extension of this technique will allow 3D reconstruction of the large-scale CME magnetic fields that directly couple with the Earth's magnetosphere (Bz negative) prior to their Earth arrival. It will also allow a low-resolution determination of 3D magnetic field components *throughout the heliosphere* in order to determine interactions at other locations such as at planets and comets.

Our IPS analyses provide volumetric density (also velocity) data in real time made available on our Web sites from data from the Japanese (STELab, Nagoya University) IPS arrays operate (currently from May-December). That STELab IPS analyses can roughly match spacecraft densities (and velocities) measured *in situ* has been shown in many articles (Bisi *et al.*, 2007; 2009a,c). We have also successfully provided these same densities using IPS data from a currently-operating Ootacamund (Ooty) array in India, and it is this system that will be most nearly like the IPS system developed for use at MWA or LOFAR. Current efforts are underway to determine the validity of the Ooty data during the current period of solar minimum activity. So far these analyses have not been very successful even though periods during solar maximum have been reconstructed well (Bisi *et al.*, 2008a; 2009b) (Figure 3 and Figure 4 are from these articles.). The SMEI instrument has also provided extremely fine measurements of archival heliospheric density data for select intervals (Jackson *et a*l., 2008a, Bisi *et al.*, 2008b), and in the latter article these analyses were used to drive a time-dependent 3-D MHD model that compares successfully with the kinematic model usually used as a kernel in the UCSD 3-D reconstruction program. We continue to upgrade these volumetric density data at ever-higher resolution over the whole of the SMEI data set using different displays

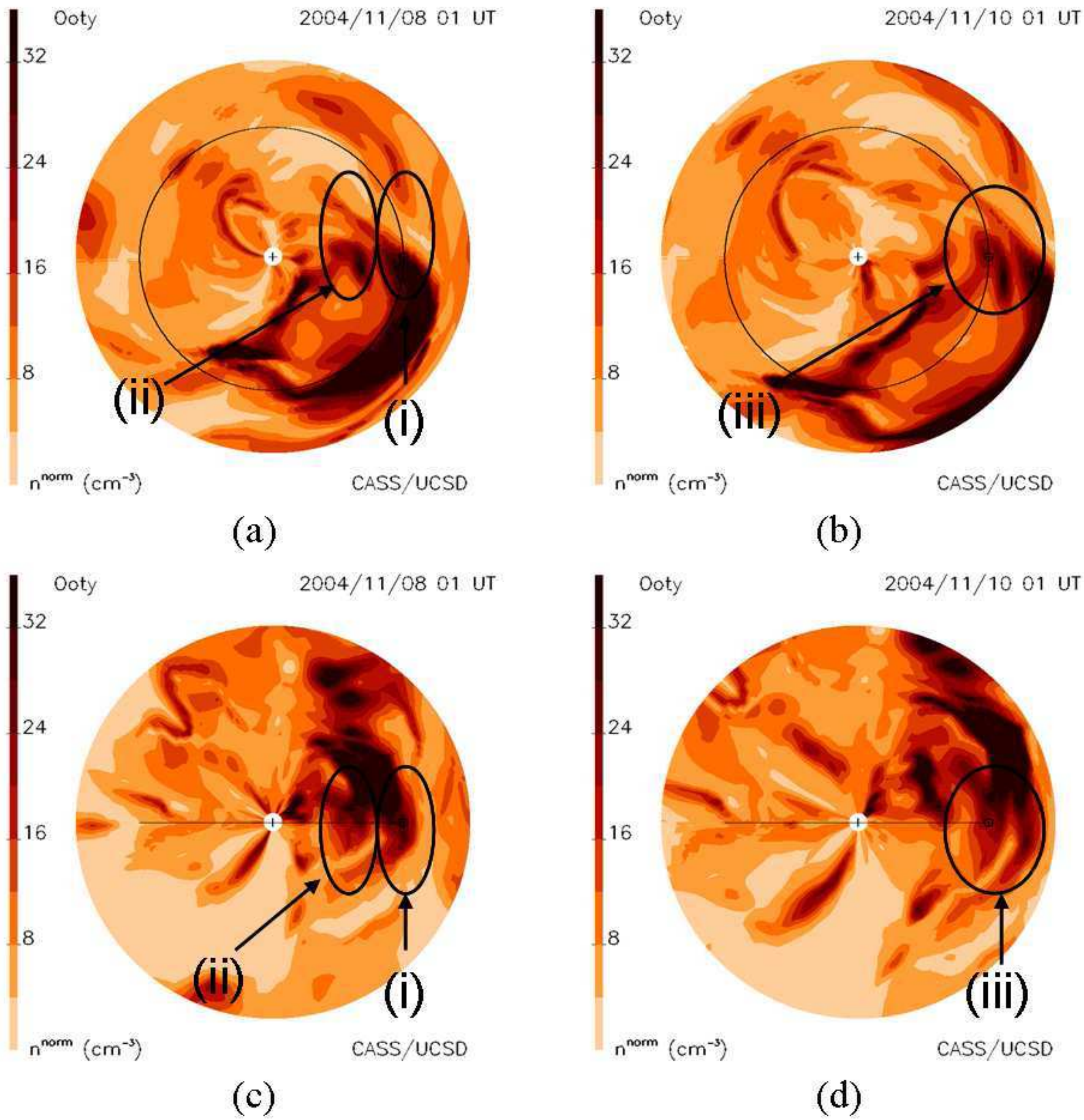


Figure 4. Summary figure of the Ooty ecliptic-, **(a)** and **(b)**, and meridional-, **(c)** and **(d)**, cuts through the 3D density reconstruction out to 1.5AU at the times shown. Various features of the several CMEs that pass the Earth are circled in the images which are also related to features seen in the LASCO coronagraphs. Earth's orbit is shown as a near-circle or line with the Earth, ⊕, indicated on each plot. The expected r^{-2} density fall-off scaling is used to normalize structures at different radii. Density contours to the left of each image are scaled to 1AU (from Bisi *et al*., 2009b).

and analyses to certify these results (Jackson *et al*., 2009a,b,c,d,e). These data analyses are available on our Website and the SMEI brightness data that allows the SMEI proxy density to be derived (through mid 2009) is now available on line in image format (see **http://smei.ucsd.edu/**). How these time-dependent analyses are performed (Hick and Jackson, 2004) are now written-up in a comprehensive article (Jackson *et al*., 2009c). The IPS density volumes (either from STELab or

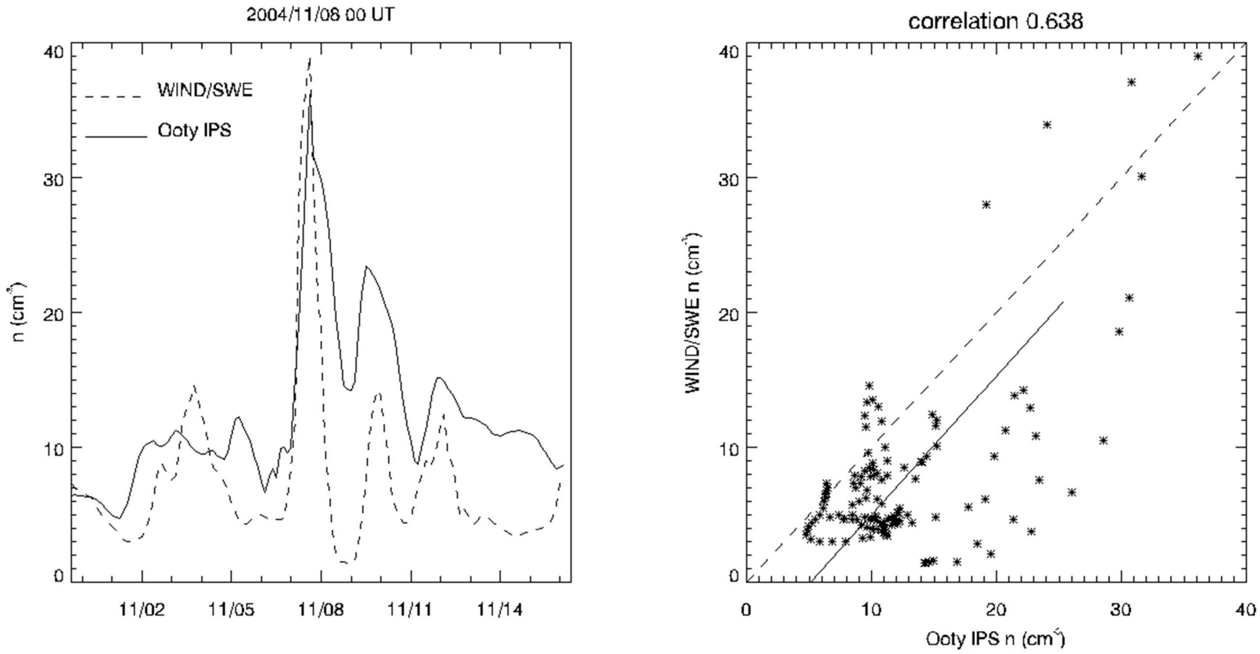


Figure 5. A time-series comparison of the 3D Ooty reconstruction evaluated at the Sun-Earth L_1-Point and compared with solar wind plasma measurements taken by the Wind spacecraft in the left-hand plot. The right-hand plot shows a correlation of the time series (from Bisi *et al*., 2009).

from other IPS radio sites) will allow a test of the feasibility of FR magnetic field reconstruction when ground-based FR observations become available, and if SMEI data are available at the same time, these data can be used to determine an even better density proxy for magnetic field reconstruction results.

Not being able to test available algorithms to invert real FR measurements has led our group to invent yet another technique to be used in forecasting solar wind parameters at the Earth. In this we have incorporated measurements of *in-situ* solar wind velocity from the ACE spacecraft so that it, plus remote sensing data sets, can be used simultaneously to converge to a forecast measurement at Earth. This allows an extremely good fit of remotely-sensed and *in-situ* inverted data up to the time that there is no longer available *in-situ* measurements. Not only does the forecast algorithm have far less work to do following the end of the *in-situ* measurements, but potentially the system also allows a quick calibration of the remote-sensing parameters.

Figure 6 (from Hick *et al*., 2009) gives an example of the velocity convergence for European Incoherent SCATter (EISCAT) IPS velocity measurement observations (Bisi *et al*., 2009d) for the time this European instrument system was run in campaign mode (April-May, 2007). That there is *any* correlation between remotely-sensed IPS velocities for these high-radio-frequency (~1000 MHz) observations, and those measured *in situ* is astounding in it own right. This attests to how well extremely good (but very sparse) IPS velocity measurements can be inverted to give good 3D time-dependent results using the UCSD 3D reconstruction algorithm. The addition of the *in-situ* measurements to provide better convergence in velocity does so with little change in the overall solar wind structure that is remotely viewed, and this also says that global solar wind structure is not unduly affected by the immediate measurements near Earth even though these are used in the line-of-sight measurements that determine the global structure. A far more comprehensive explanation of this type of forecast algorithm and its use with STELab IPS data (see Figure 7) has been submitted

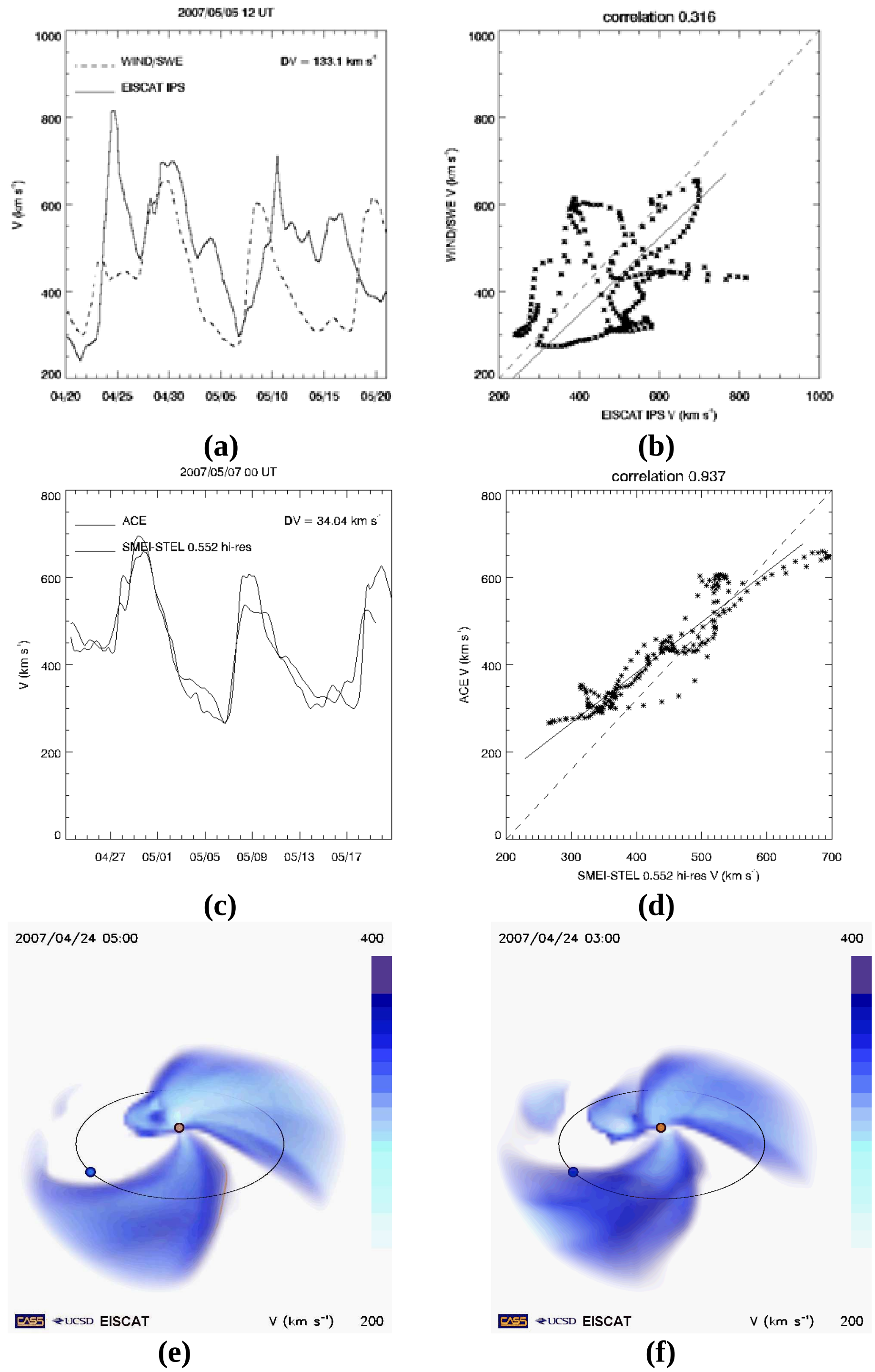
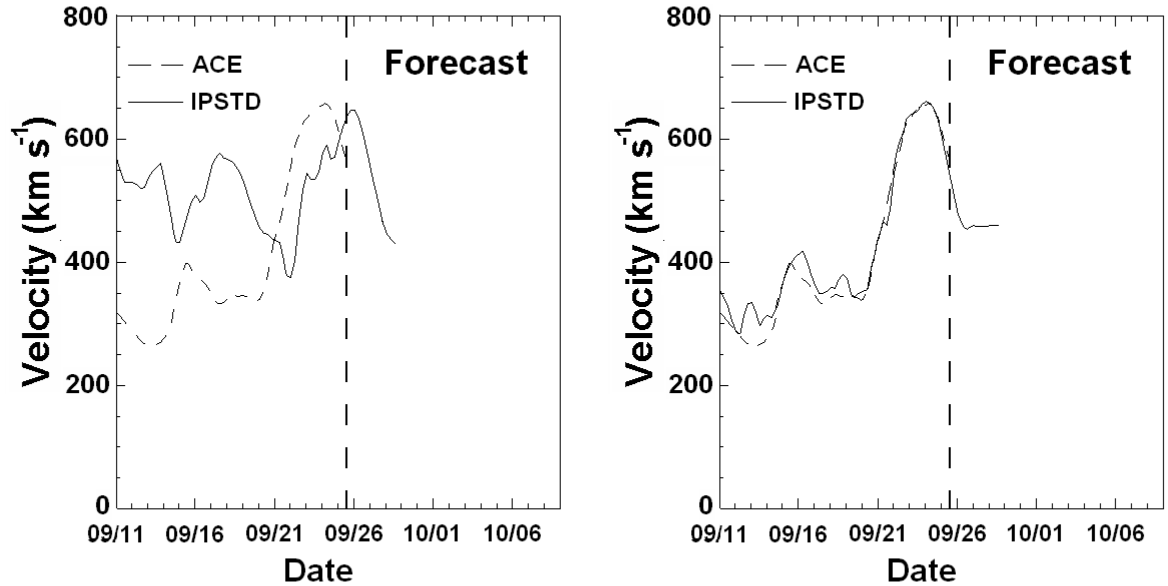


Figure 6. (a) and **(b)** Velocity time series from the EISCAT time-dependent 3D reconstructions and its correlation. **(c)** and **(d)** The same velocity time series with *in-situ* measurements added to the 3D time-dependent 3D reconstructions. **(e)** and **(f)** Velocity as a remote observer would observe it from about 45° West of the Sun-Earth line and 30° above the ecliptic. Only the slow velocities are shown, and these are located primarily in the ecliptic plane. The low velocities shown in this time-dependent 3D-reconstruction form the Archimedean spiral structure often present in the slow solar wind. The left panel (e) shows 3D reconstructions of (a) and (b), with (c) and (d) shown right in (f). There is little difference noted in the two sets of data except along the radial that incorporates the Sun-Earth line.



(a) (b)

Figure 7. Velocity time series from the STELab time-dependent 3-D reconstruction forecast analysis for CR 2061 using only data prior to the cut-off time of 12:00 UT on 25 September 2007 (shown as a vertical dashed line). Forecast values appear to the right of this line. **(a)** Analysis where only IPS remote-sensing data are used. These give a very poor correlation with the in-situ measurements shown as a dotted line. **(b)** Analysis where *in-situ* measurements are also included. This analysis gives an extremely good correlation (0.99) with *in-situ* velocities up to the time none are available, and considerably better forecast correlations up to 3 days following the time of *in-situ* data cut-off (from Jackson *et al*., 2009f).

and is now under review at Solar Physics (Jackson *et al*., 2009f). This article shows that a substantial enhancement in velocity forecast capability arises using the inclusion of the *in-situ* measurements for STELab remotely-sensed velocities. We expect that this enhancement comes not only from a smoothing of the measurements near Earth into those remotely-sensed, but that the additional information added near Earth along each line of sight adds information to the line of sight that then extends more precise measurements to the volume that can only be accessed remotely.

IPS velocity measurements from both the remote sensing 3-D reconstructions and *in-situ* measurements give very similar results. Thus for velocity measurements, a calibration using the *in-situ* measurements is not as important as for other solar wind parameters. However, for density measurements from both remote-sensing Thomson-scattering (SMEI) and IPS g-level measurements there are several parameters that set the level of the current 3D results from existing solar wind average values. These solar wind modeling parameters are far-better obtained from an iterated composite using both remotely-sensed observations and *in-situ* measurements density, and this ability is now shown possible from these analyses.

For space-weather forecast analyses it is clearly possible to use a similar approach for any plasma parameter that can be measured or inferred remotely. This includes density inferred from the IPS *g*-level proxy, or from brightness measured from electron Thomson-scattering as from SMEI. It also applies to Faraday rotation observations (planned using the MWA and/or LOFAR systems) that remotely measure a combination of density and magnetic-field strength parallel to the LOS, and that have been shown to allow a 3-D inversion of the heliospheric magnetic-field vector (Jackson *et al*., 2008b).

References:

Bisi, M.M., Jackson, B.V., Hick, P.P., Buffington, A., and Clover, J.M., 2007, Coronal mass ejection reconstructions from interplanetary scintillation data using a kinematic model: a brief review, in: M. Duldig *et al*., eds., *Adv. in Geosciences*, **14**, 161.

Bisi, M.M., Fallows, R.A., Manoharan, P.K., Dorrian, G.D., Jackson, B.V., Clover, J.M., Hick, P.P., Buffington, A., and Breen, A.R., 2008a, Solar Wind and CME Studies of the Inner Heliosphere Using IPS Data from ORT and EISCAT, to the 5th Asia-Oceania Geophysical Society General Assembly Proceedings, *Adv. in Geosciences*, August 2008 (in press).

Bisi, M.M., Jackson, B.V., Hick, P.P., Buffington, A., and Clover, J.M., 2008b, '3D Reconstructions of the Early November 2004 CDAW Geomagnetic Storms: Preliminary analysis of STELab IPS speed and SMEI density', *J. Geophys Res. – Space Physics Special Edition – Geomagnetic Storms of Solar Cycle 23*, **113**, A00A11, doi:10.1029/2008JA013222.

Bisi, M.M., Jackson, B.V., Buffington, A., Clover, J.M., Hick, P.P., and Tokumaru, M., 2009a, 'Low-Resolution STELab IPS 3D Reconstructions of the Whole Heliospheric Interval and Comparison with in-Ecliptic Solar Wind Measurements from STEREO and Wind Instrumentation', *Sol. Phys*., **256**, 201, doi:10.1007/s11207-009-9350-9.

Bisi, M.M., Jackson, B.V., Clover, J.M., Manoharan, P.K., Tokumaru, M., Hick, P.P., and. Buffington, A., 2009b, '3D reconstructions of the early-November 2004 CDAW geomagnetic storms: analysis of Ooty IPS speed and density data', *Annales Geophysicae*, **27**, 4479.

Bisi, M.M., Jackson, B.V., Clover, J.M., Hick, P.P., Buffington, A., and Tokumaru, M., 2009c, 'A Summary of 3D Reconstructions of the Whole Heliosphere Interval and Comparison with in-Ecliptic Solar Wind Measurements from STEREO, ACE, and Wind Instrumentation', XXVIIth IAU General Assembly, August 2009, *Highlights of Astronomy*, **15**, 119.

Bisi, M.M., Jackson, B.V., Breen, A.R., Dorrian, G.D., Fallows, R.A., Clover, J.M., and Hick, P.P., 2009d, 'Three-Dimensional (3-D) Reconstructions of EISCAT IPS Velocity Data in the Declining Phase of Solar Cycle 23', *Solar Phys*. (submitted).

Dunn, T., Jackson, B.V., Hick, P.P., Buffington, A., and Zhao, X.P., 2005, 'Comparative Analyses of the CSSS Calculation in the UCSD Tomographic Solar Observations', *Solar Phys.* **227**, 339-353.

Hick, P.P., and Jackson, B.V., 2004, 'Heliospheric tomography: an algorithm for the reconstruction of the 3D solar wind from remote sensing observations', *Proc. SPIE* **5171**, 287−297.

Hick, P.P., Jackson, B.V., Bisi, M.M., Clover, J.M., and Buffington, A., 2009, 'Faraday Rotation: Expected Possible Analyses from Polarized Radio Sources and Other Matters' - Remote Sensing of the Inner Heliosphere Workshop, Aberystwyth, Wales, May 2009.

Jackson, B.V., Buffington, A., Hick, P.P., Wang, X. and Webb, D., 2006, ‘Preliminary three-dimensional analysis of the heliospheric response to the 28 October 2003 CME using SMEI white-light observations’, *J. Geophys. Res.* 111, A4, A04S91.

Jackson, B.V., Bisi, M.M., Hick, P.P., Buffington, A., Clover, J.M., and Sun, W., 2008a, “Solar Mass Ejection Imager (SMEI) 3D Reconstruction of the 27-28 May 2003 CME Sequence”, to the (CDAW) Journal of Geophysical Research – Space Physics Special Edition - Geomagnetic Storms of Solar Cycle 23, *J. Geophys Res*., **113**, A00A15, doi:10.1029/2008JA013224.

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., and Clover, J.M., 2008b, NSF UARS-UAF Meeting presentation, September 2008, Haystack Observatory, MA, USA.

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., and Clover, J.M., 2009a, ‘SMEI direct, 3D-reconstruction sky maps and volumetric analyses, and their comparison with SOHO and STEREO observations’, *Annales Geophysicae*, **27**, 4097.

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., Clover, J.M., Hamilton, M.S., Tokumaru, M., and Fujiki, K., 2009b, ‘3D Reconstruction of Density Enhancements Behind Interplanetary Shocks from Solar Mass Ejection Imager White-Light Observations’, *American Institute of Physics* (Solar Wind 12 Proceedings) (in press).

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., Clover, J.M., and Tokumaru, M., 2009c, ‘Solar Mass Ejection Imager (SMEI) and Interplanetary Scintillation (IPS) 3D-Reconstructions of the Inner Heliosphere’, *Adv. in Geosciences* (in press).

Jackson, B.V., Bisi, M.M., Hick, P.P., Buffington, A., Clover, J.M., Webb, D.F., and Tokumaru, M., 2009d, ‘SMEI Remote Sensing and the 3D Reconstruction of Corotating Heliospheric Structures During WHI’, International Astronomical Union, Joint Discussion 16 (JD16) on the Whole Heliosphere Interval (WHI), Rio de Janeiro, Brazil, August 2009 (oral presentation).

Jackson, B.V., Hick, P.P., A. Buffington, A., Bisi, M.M., Clover, J.M., Hamilton, S., Tokumaru, M., and Fujiki, K., 2009e, ‘The Solar Mass Ejection Imager (SMEI) 3D-reconstruction of density enhancements behind interplanetary shocks’, International Living With a Star (ILWS) Workshop, Ubatuba – SP, Brazil, October 2009 (oral presentation).

Jackson, B.V., Hick, P.P., Bisi, M.M., Clover, J.M., and Buffington, A., 2009f, ‘Inclusion of in-situ Velocity Measurements in the UCSD Time-Dependent Tomography to Constrain and Better-Forecast Remote-Sensing Observations’, *Solar Phys*. (submitted).

Jensen, E.A., Mulligan, T., Jackson, B.V. and Tokumaru, M., 2006, ‘3-D Magnetic Field Geometry of the October 28, 2003 ICME: Comparison with SMEI White-Light Observations’, *EOS Trans. AGU* 87(52), Fall Meet. Suppl., Abstract SH33A-0397.

Jensen, E.A., Hick, P.P., Bisi, M.M., Jackson, B.V., Clover, J., and Mulligan, T.L., 2009, ‘Faraday Rotation Response to Coronal Mass Ejection Structure’, *Solar Phys*., (submitted).

The following personnel benefited from or have been partially funded on this AFOSR contract:

Dr Bernard V. Jackson	UCSD Research Scientist
Dr. Mario Bisi	UCSD Post-doctoral fellow
Mr. Zachary Vaughn	UCSD Undergraduate Student
Mr. John Clover	UCSD Undergraduate Student/UCSD Staff Researcher
Mr. George Megally	UCSD Undergraduate Student
Mr. Sarahas Hamilton	UCSD Undergraduate Student
Mr. Sarang Ratanjee	UCSD Undergraduate Student

Journal Articles and pertinent publications associated with this AFOSR contract:

2007:

Bisi, M.M., Jackson, B.V., Fallows, R.A., Breen, A.R., Hick, P.P., Wannberg, G., Thomasson, P., Jordan, C. and Dorrian, G.D., 2007, 'Combined STELab, EISCAT, ESR, and MERLIN IPS Observations of the Solar Wind', *Proc. SPIE* 6689, 668911, 1−10, doi: 10.1117/12.735443.

Bisi, M.M., Fallows, R.A., Breen, A.R., Habbal, S.R., and Jones, R.A., 2007, 'Large-scale structure of the fast solar wind', *J. Geophys. Res*. – Space Physics, 112, A06101, doi:10.1029/2006JA012166.

Bisi, M.M., Jackson, B.V., Hick, P.P., Buffington A., and Clover, J.M., 2007, 'Coronal Mass Ejection (CME) Reconstructions from Interplanetary Scintillation (IPS) Data Using a Kinematic Model: A Brief Review', *Adv. in Geosciences*, **14**, 161.

Buffington, A., Morrill, J.S., Hick, P.P., Howard, R.A., Jackson B.V., and Webb, D.F., 2007, 'Analysis of the Comparative Responses of SMEI and LASCO', *Proc. SPIE* 6689, 66890B, 1, doi:10.1117/12.734658.

Fallows, R.A., Breen, A.R., Bisi, M.M., Jones, R.A., and Dorrian, G.D., 'Interplanetary Scintillation Using EISCAT and MERLIN: Extremely-Long Baselines at Multiple Frequencies', Proceedings of the International Colloquium "Scattering and Scintillation in Radio Astronomy", in *Astronomical and Astrophysical Transactions*, I. Chasei and V. Shishov, eds., 26:6, 489-500, doi:10.1080/10556790701612221.

Harra, L.K., Crooker, N.U., Mandrini, C.H., van Driel-Gesztelyi, L., Dasso, S., Wang, J., Elliott, H., Attril, G., Jackson, B.V., and Bisi, M.M., 2007, 'How does large flaring activity from the same active region produce oppositely directed magnetic clouds?', *Solar Phys*., **244**, 95-114, doi:10.1007/s11207-007-9002-x.

Hick, P.P., Buffington, A. and Jackson, B.V., 2007, 'A procedure for fitting point sources in SMEI white-light full-sky maps', *Proc. SPIE* 6689, 66890C, 1−8, doi:10.1117/12.734808.

Jackson, B.V., Boyer, J.A., Hick, P.P., Buffington, A., Bisi, M.M., and Crider, D.H., 2007, Analysis of Solar Wind Events Using Interplanetary Scintillation (IPS) Remote Sensing 3D Reconstructions And Their Comparison at Mars”, *Solar Phys.* 241 (2), 385-396, doi: 10.1007/s11207-007-0276-9.

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M. and Jensen, E.A., 2007, ‘SMEI Observations in the STEREO Era’, *Proc. SPIE*, 6689, 66890G, 1−14, doi: 10.1117/12.734870.

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., Kojima M., and Tokumaru, M., 2007, ‘Comparison of the extent and mass of CME events in the interplanetary medium using IPS and SMEI Thomson scattering observations’, Proceedings of the International Colloquium “Scattering and Scintillation in Radio Astronomy", in *Astronomical and Astrophysical Transactions*, I. Chasei and V. Shishov, eds., 26:6, 477–487, doi: 10.1080/10556790701612221.

Jones, R.A., Canals, A., Breen, A.R., Fallows, R.A., Bisi, M.M., and Lawrence, G., 2007, ‘Interaction between coronal mass ejections and the solar wind’, *J. Geophysical Res*., 112, A08107, doi:10.1029/2006JA011875.

Kojima, M., Tokumaru, M., Fujiki, K., Hayashi, K., and Jackson, B.V., 2007, ‘IPS tomographic observations of 3D solar wind structure’, in I. Chashei, and V. Shishov, eds. Scattering and Scintillation in Radio Astronomy, *Astronomical and Astrophysical Transactions*, **26:6**, 467-476 doi:10.1080/10556790701596200.

Tokumaru, M., Kojima, M., Fujiki, K., Yamashita, Y, and Jackson, B.V., 2007, ‘The source and propagation of the interplanetary disturbance associated with the full-halo coronal mass ejection on 2003 October 28’, *J. Geophys. Res*., 112, A05106, doi:10.1029/2006JA012043.

2008:

Bisi, M.M., Jackson, B.V., Hick, P.P., Buffington, A., Odstrcil, D., and Clover, J.M., 2008, ‘3D Reconstructions of the Early-November 2004 CDAW Geomagnetic Storms: Analyses of STELab IPS speed and SMEI density data’, (CDAW) *J. Geophys. Res*. Special Edition - Geomagnetic Storms of Solar Cycle 23, 113, A00A11, doi:10.1029/2008JA013222.

Breen, A.R., Fallows, R.A., Bisi, M.M., Jones, R.A., Jackson, B.V., Kojima, M., Dorrian, G.D., Middleton, H.R., Thomasson, P., and Wannberg, G., 2008, ‘The solar eruption of 2005 May 13 and its effects: Long-baseline interplanetary scintillation observations of the Earth-directed coronal mass ejection’, *Astrophys. J. Letts*., 683, L79 – L82, doi:10.1086/591520.

Buffington, A., Bisi, M.M., Clover, J.M., Hick, P.P., Jackson, B.V., and Kuchar, T.A., 2008, ‘Analysis of Plasma-Tail Motions for Comets C/2001 Q4 (NEAT) and C/2002 T7 (LINEAR) using Observations from SMEI’, *Astrophys. J.*, 677, 798-807.

Jackson, B.V., Bisi, M.M., Hick, P.P., Buffington, A., Clover, J.M., and Sun, W., 2008, ‘Solar Mass Ejection Imager (SMEI) 3D Reconstruction of the 27-28 May 2003 CME Sequence’, (CDAW)

J. Geophys. Res. – Special Edition - Geomagnetic Storms of Solar Cycle 23, 113, A00A15, doi:10.1029/2008JA013224.

Kuchar, T. A., Buffington, A., Arge, C. N., Hick, P. P., Howard, T. A., Jackson, B. V., Johnston, J. C., Mizuno, D. R., Tappin, S. J., and Webb, D. F., 2008, 'Observations of a Comet Tail Disruption Induced by the Passage of a CME', *J. Geophys. Res*., 113, A04101, doi:10.1029/2007JA012603.

Odstrcil, D., Pizzo, V.J., Arge, C.N., Bisi, M.M., Hick, P.P., Jackson, B.V., Ledvina, S.A., Luhmann, J.G., Linker, J.A., Mikic, Z., and Riley, P., 2008, 'Numerical Simulations of Solar Wind Disturbances by Coupled Models', *ASP Conference Series Proceedings*, **385**, 167-173.

2009:

Bisi, M.M., Fallows, R.A., Manoharan, P.K., Dorrian, G.D., Jackson, B.V., Clover, J.M., Hick, P.P., Buffington, A., and Breen, A.R., 2009, 'Solar Wind and CME Studies of the Inner Heliosphere Using IPS Data from ORT and EISCAT', to the 5th Asia-Oceania Geophysical Society General Assembly Proceedings, *Advances in Geosciences*, August (2008). (in press).

Bisi, M.M., B.V. Jackson, A. Buffington, J.M. Clover, P.P. Hick, and M. Tokumaru, 2009, 'Low-Resolution STELab IPS 3D Reconstructions of the Whole Heliosphere Interval and Comparison with in-Ecliptic Solar Wind Measurements from STEREO and Wind Instrumentation', *Solar Phys*. - STEREO Science Results at Solar Minimum Topical Issue, **256**, 201-217, doi:10.1007/s11207-009-9350-9.

Bisi, M.M., Jackson, B.V., Clover, J.M., Manoharan, P.K., Tokumaru, M., Hick, P.P., and. Buffington, A., 2009, '3D reconstructions of the early-November 2004 CDAW geomagnetic storms: analysis of Ooty IPS speed and density data', *Annales Geophysicae*, **27**, 4479.

Bisi, M.M., Jackson, B.V., Clover, J.M., Tokumaru, M., and Fujiki, K., 2009, 'Large-Scale Heliospheric Structure during Solar-Minimum Conditions using a 3D Time-Dependent Reconstruction Solar-Wind Model and STELab IPS Observations', in-press, *American Institute of Physics* (Solar Wind 12 Proceedings).

Bisi, M.M., Jackson, B.V., Clover, J.M., Hick, P.P., and Buffington, A., 2009, '3D Reconstructions of the Whole Heliosphere Interval and Comparison with in-Ecliptic Solar Wind Measurements from STEREO, ACE, and Wind Instrumentation: a Brief Summary', XXVIIth IAU General Assembly, August 2009, *Highlights of Astronomy*, **15**, 119.

Bisi, M.M., Jackson, B.V., Breen, A.R., Dorrian, G.D., Fallows, R.A., Clover, J.M., and Hick, P.P., 2009, 'Three-Dimensional (3-D) Reconstructions of EISCAT IPS Velocity Data in the Declining Phase of Solar Cycle 23', *Solar Phys*. (submitted).

Bisi, M.M., Breen, A.R., Jackson, B.V., Fallows, R.A., Walsh, A.P., Mikic, Z., Riley, P., Owen, C.J., Gonzalez-Esparza, A., Aguilar-Rodriguez, E., Morgan, H., Jensen, E.A., Wood, A.G., Tokumaru, M., Manoharan, P.K., Chashei, I.V., Giunta, A.S., Linker, J.A., Shishov, V.I.,

Tyul'bashev, S.A., Agalya, , G., Glubokova, S.K., Hamilton, M.S., Fujiki, K., Hick, P.P., Clover, J.M., Pinter, B., 2009, 'From the Sun to the Earth: the 13 May 2005 Coronal Mass Ejection', *Solar Phys*. (submitted).

Buffington, A., Bisi, M.M., Clover, J.M., Hick, P.P., Jackson, B.V., Kuchar, T.A., and Price, S.D., 2009, 'Measurements of the Gegenschein brightness from the Solar Mass Ejection Imager (SMEI)', *Icarus*, 203, 124, doi:10.1016/j.icarus.2009.04.007.

Buffington, A., Bach, K.G., Bach, B.W., Bach, E.K., Bisi, M.M., Hick, P.P., Jackson, B.V., and Klupar, P.D., 2009, 'Fabrication and Test of a Diamond-turned Mirror Suitable for a Spaceborne Photometric Heliospheric Imager', *Proc. SPIE* **6689**, 66890B, 1−6, doi: 10.1117/12.734658.

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., and Clover, J.M., 2009, 'SMEI direct, 3D-reconstruction sky maps and volumetric analyses, and their comparison with SOHO and STEREO observations', *Annales Geophysicae*, **27**, 4097.

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., Clover, J.M., Tokumaru, M., and Fujiki, K., 2009, '3D Reconstruction of Density Enhancements Behind Interplanetary Shocks from Solar Mass Ejection Imager White-Light Observations', *American Institute of Physics* (Solar Wind 12 Proceedings) (in press).

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., Clover, J.M., and Tokumaru, M., 2009, 'Solar Mass Ejection Imager (SMEI) and Interplanetary Scintillation (IPS) 3D-Reconstructions of the Inner Heliosphere', *Adv. in Geosciences* (in press).

Jackson, B.V., Hick, P.P., Bisi, M.M., Clover, J.M., and Buffington, A., 2009, 'Inclusion of in-situ Velocity Measurements in the UCSD Time-Dependent Tomography to Constrain and Better-Forecast Remote-Sensing Observations', *Solar Phys*. (submitted).

Jackson, B.V., Buffington, A., Hick, P.P., Bisi, M.M., and Clover, J.M., 2009, A Heliospheric Imager for Deep Space: Lessons Learned from Helios, SMEI, and STEREO', *Solar Phys*. (submitted).

Jensen, E.A., Hick, P.P., Bisi, M.M., Jackson, B.V., Clover, J., and Mulligan, T.L., 2009, 'Faraday Rotation Response to Coronal Mass Ejection Structure', *Solar Phys*., (submitted).

Webb, D.F., Howard, T.A., Fry, C.D., Kuchar, T.A., Odstrcil, D., Jackson, B.V., Bisi, M.M., Harrison, R.A., Morrill, J.S., Howard, R.A., and Johnston, J.C., 2009, 'Study of CME Propagation in the Inner Heliosphere: SMEI and STEREO HI Observations of the January 2007 Events', *Solar Phys*.- STEREO Special Issue, 256, 239, doi:10.1007/s11207-009-9351-8.

Webb, D. F., Howard, T. A., Fry, C. D., Kuchar, T. A., Mizuno, D. R., Johnston, J. C., and Jackson, B. V., 2009, 'Studying Geoeffective ICMEs between the Sun and Earth: Space Weather Implications of SMEI Observations', *Space Weather*, 7, S05002, doi:10.1029/2008SW000409.

Conference Abstracts associated with this AFOSR contract:

2007:

Bisi, M.M., Jackson, B.V., Hick, P.P., and Buffington, A., 2007, CME Reconstructions Using Interplanetary Scintillation Data" - LWS (Living With a Star) Geostorm CDAW (Coordinated Data-Analysis Workshop) and Conference, March 2007, Melbourne, FL, U.S.A. (oral presentation).

Bisi, M.M., B.V. Jackson, P.P. Hick, and A. Buffington, 2007, 'CME Reconstructions Using Interplanetary Scintillation Data" - 4th Asia-Oceania Geophysical Society General Assembly, Bangkok, Thailand, July/August 2007 (oral presentation).

Bisi, M.M., Jackson, B.V., Fallows, R.A., Breen, A.R., Hick, P.P., Wannberg, G., Thomasson, P., Jordan, C.A., and Dorrian, G.D., 2007, 'Combined STELab, EISCAT, ESR and MERLIN observations of the solar wind', SPIE Optical Engineering + Applications 2007 meeting, San Diego, CA, U.S.A., August 2007 (oral presentation).

Bisi, M.M., Jackson, B.V., Manoharan, P.K., Fallows, R.A., Kojima, M., Tokumaru, M., Breen, A.R., Hick, P.P., Dorrian, G.D., Clover, J.M., and Buffington, A., 2007, '3D reconstructions using interplanetary scintillation (IPS) and the solar mass ejection imager (SMEI) data', SCOSTEP International CAWSES Symposium, Kyoto, Japan, October 2007 (poster).

Bisi, M.M., 2007, 'Discrepancies and problems in the IPS data obtained at different sites', Toyokawa IPS Workshop, STELab, Toyokawa, Japan, 30-31 October 2007 (oral discussion session).

Bisi, M.M., Jackson, B.V., Breen, A.R., Fallows, R.A., Feynman, J., Clover, J.M., Hick, P.P., and Buffington, A., 2007, 'IPS Observations of the Inner-Heliosphere and their Comparison with Multi-Point In-situ Measurements', AGU (American Geophysical Union) Fall Meeting, December 2007, San Francisco, CA, U.S.A. (poster).

Breen, A.R., Fallows, R.A., Bisi, M.M., and Dorrian, G.D., 2007, '3D structure of the inner heliosphere - a new view from radio scintillation observations' - Royal Astronomical Society National Astronomy Meeting, Preston, England, April 2007 (poster).

Breen, A.R., Bisi, M.M., Fallows, R.A., and Dorrian, G.D., 2007, 'Extremely long baseline Interplanetary Scintillation studies of the solar wind', 4th Asia-Oceania Geophysical Society General Assembly, Bangkok, Thailand, July/August 2007 (oral presentation).

Breen, A.R., Fallows, R.A., Dorrian, G.D., and Bisi, M.M., 2007, 'Extremely long-baseline interplanetary scintillation measurements – a tool for probing solar wind structure' - EISCAT International Workshop 2007, Marienheim, Åland, August 2007 (oral presentation).

Breen, A.R., Davis, C.J., Dorrian, G.D., Fallows, R.A., Morgan, H., Bisi, M.M., Middleton, H.R., Whittick, E., Bewsher, D., Harrison, R.A., Crothers, S., Davis, J., Eyles, C., Thomasson,

P., and Wannberg, G., 2007, 'A new view of space weather – combining IPS and STEREO observations of the solar wind with studies of ionospheric consequences', SCOSTEP International CAWSES Symposium, Kyoto, Japan, October 2007 (oral presentation).

Breen, A.R., Davis, C.J., Dorrian, G.D., Fallows, R.A., Morgan, H., Bisi, M.M., Middleton, H.R., Whittick, E., Bewsher, D., Harrison, R.A., Crothers, S., Davis, J., Eyles, C., Thomasson, P., and Wannberg, G., 2007, 'A new view of space weather - combining IPS and STEREO HI observations of the solar wind with studies of ionospheric consequences', Toyokawa IPS Workshop, STELab, Toyokawa, Japan, 30-31 October 2007 (oral presentation).

Breen, A.R., Dorrian, G.D., Bisi, M.M., Davis, C.J., Fallows, R.A., Morgan, H., and Harrison, R.A., 2007, 'A 3D view of coronal mass ejections in interplanetary space', AGU (American Geophysical Union) Fall Meeting, December 2007, San Francisco, CA, U.S.A. (poster).

Buffington, A., Bisi, M.M., Clover, J.M., Hick, P.P., and Jackson, B.V., 2007, 'Analysis and Interpretation of Comet Measurements from SMEI', AGU (American Geophysical Union) Fall Meeting, December 2007, San Francisco, CA, U.S.A. (poster).

Dorrian, G.D., Breen, A.R., Fallows, R.A., Bisi, M.M., Thomasson, P., and Wannberg, G., 2007, 'Equatorwards expansion of the Fast Solar Wind' - Royal Astronomical Society National Astronomy Meeting, Preston, England, April 2007 (poster).

Dorrian, G.D., Breen, A.R., Fallows, R.A., Bisi, M.M., Thomasson, P., and Wannberg, G., 2007, 'Equatorwards expansion of the interplanetary magnetic field', EISCAT International Workshop 2007, Marienheim, Åland, August 2007 (poster).

Hick, P.P., Jackson, B.V., Bisi, M.M., Buffington, A., and Clover, J.M., 2007, 'UCSD Heliospheric Tomography model at CCMC: current status and future plans', The 4th CCMC Community Workshop, Arecibo Observatory, Puerto Rico, November 2007 (poster).

Jackson, B.V., Bisi, M.M., Hick P.P., and Buffington, A., 2007, 'CME 3D Reconstructions Using Solar Mass Ejection Imager and Interplanetary Scintillation Data', presented at 210th AAS/SPD meeting, Honolulu, 28-31 May 2007. BAAS, 39, #1, p. 244 (poster).

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., and Jensen, E.A., 2007, 'Solar Mass Ejection Imager (SMEI) Analysis of the 20 January 2005 CME', SHINE (Solar, Heliospheric & INterplanetary Environment) Workshop, Whistler, BC, Canada, July/August 2007 (poster).

Jackson, B.V., Buffington, A., Hick, P.P., Bisi, M.M., and Jensen, E.A., 2007, 'SMEI Observations in the STEREO Era', Proceedings SPIE Optical Engineering + Applications 2007 meeting, August 2007 (oral presentation).

Jackson, B.V., Buffington, A., Hick, P.P., Bisi, M.M., and Jensen, E.A., 2007, 'STEREO-Era Solar Mass Ejection Imager (SMEI) Observations', Living With a Star (LWS) Conference, Boulder, CO, U.S.A., September 2007 (poster).

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., Jensen, E.A., Kojima, M., and Tokumaru, M., 2007, 'CME 3D Reconstructions Using Solar Mass Ejection Imager and Interplanetary Scintillation Data and Extrapolation to Ulysses', SCOSTEP International CAWSES Symposium, Kyoto, Japan, October 2007 (oral presentation).

Jackson, B.V., Bisi M.M., and Clover J.M., 2007, 'SMEI – IPS – Ulysses – STEREO: Current UCSD Comparison Progress' - Toyokawa IPS Workshop, STELab, Toyokawa, Japan, 30-31 October 2007 (oral presentation).

Jackson, B.V., Bisi, M.M., Hick, P.P., Buffington, A., Clover, J.M., and Feynman, J., 2007, 'Inner-heliosphere SMEI observations and their comparison with multi-point in-situ measurements', 2007, AGU (American Geophysical Union) Fall Meeting, December 2007, San Francisco, CA, U.S.A. (oral presentation).

Jensen, E.A., Jackson, B.V., Bisi, M.M., Buffington, A., Clover, J.M., and Mulligan, T.L., 2007, 'Vital Statistics From an Initial Combination of 3D Tomographic Data and ACE During CME Crossings', SHINE (Solar, Heliospheric & INterplanetary Environment) Workshop, Whistler, BC, Canada, July/August 2007 (poster).

Jensen, E.A., Jackson, B.V., Bisi, M.M., and Hick, P.P., 2007, 'Challenges to Multipoint Faraday Rotation Observations of CMEs', SCOSTEP International CAWSES Symposium, Kyoto, Japan, October 2007 (poster).

Webb, D.F., Howard, T.A., Jackson B.V., and Johnston, J.C., 2007, 'SMEI Observations of ICMEs Driving CDAW Storms', presented at the at the Living With a Star Geostorm CDAW and Conference, Florida Inst. of Technology, Melbourne, FL, March 8, 2007 (oral presentation).

Webb, D.F., Howard, T.A., Kuchar, T.A., Morrill, J.S., Harrison, R.A., Eyles, C.J., Howard R.A., and Johnston, J.C., 2007, 'First Combined CME Observations: LASCO, SMEI & Stereo SECCHI Hi's', presented at 210th AAS/SPD meeting, Honolulu, 28-31 May 2007. BAAS, 39,#1, p. 244 (oral presentation).

Webb, D.F., Howard, T.A., Kuchar, T.A., Morrill, J.S., Harrison, R.A., Eyles, C.J., Howard R.A., Jackson, B.V, and Johnston, J.C., 2007, 'CME Propagation in the Inner Heliosphere Using SMEI and STEREO SECCHI HI Data', SHINE (Solar, Heliospheric & INterplanetary Environment) Workshop, Whistler, BC, Canada, July/August 2007 (poster).

2008:

Bisi, M.M., Jackson, B.V., Hick, P.P., Buffington, A., and Clover, J.M., 2008, 'How Interplanetary Scintillation Observations can Enhance Heliospheric White-Light Imaging and Space-Weather Forecasting', Future Imagers Workshop – Sacramento Peak, NM, USA, April 2008 (oral presentation).

Bisi, M.M., Jackson, B.V., Buffington, A., Hick, P.P., Manoharan, P.K., and Clover, J.M., 2008, 'Solar Wind and CME Reconstructions in the Inner Heliosphere', 5th Asia-Oceania Geophysical Society General Assembly, Busan, South Korea, June 2008 (oral presentation).

Bisi, M.M., Jackson, B.V., Hick, P.P., Buffington, A., and Clover, J.M., 2008, '3D Reconstructions of the Inner Heliosphere', SHINE-GEM Meeting, Midway, UT, U.S.A., June 2008 (poster).

Bisi, M.M., Jackson, B.V., Clover, J.M., Hick, P.P., Buffington, A., Manoharan, P.K., and M. Tokumaru, M., 2008, 'Solar Wind 3D Reconstructions of the Whole Heliospheric Interval', AGU (American Geophysical Union) Fall Meeting, December 2008, San Francisco, CA, U.S.A. (poster).

Buffington, A., Jackson, B.V., Hick, P.P., and Bisi, M.M., 2008, 'A Corral-Design All-Sky Imager System for a 3D-Axis Stabilized Spacecraft Platform', Future Imagers Workshop – Sacramento Peak, NM, USA, April 2008 (oral presentation).

Buffington, A., Bisi, M.M., Clover, J.M., Hick, P.P., and Jackson, B.V., 2008, 'Measurements of the Gegenschein brightness from the Solar Mass Ejection Imager (SMEI)', AGU (American Geophysical Union) Fall Meeting, December 2008, San Francisco, CA, U.S.A. (poster).

Hick, P.P., Jackson, B.V., Bisi, M.M., Buffington, A., and Clover, J.M., 2008, 'Tomographic Reconstructions of the Solar Wind from Heliospheric Remote Sensing Observations: Density and Velocity Predictions at Mars', AGU Chapman Conference on the Solar Wind Interaction with Mars, San Diego, CA, U.S.A., January 2008 (poster).

Jackson, B.V., Hick, P.P., Buffington, A., and Bisi, M.M., 2008, 'Toward a robust method of heliospheric forecasting', Future Imagers Workshop – Sacramento Peak, NM, USA, April 2008 (oral presentation).

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., and Clover, J.M., 2008, 'The UCSD Solar Mass Ejection Imager (SMEI) Web Database', Space Weather Week, Boulder, CO, U.S.A., April-May 2008 (poster).

Jackson, B.V., Hick, P.P., Bisi, M.M., Buffington, A., and Clover, J.M., 2008, The UCSD Solar Mass Ejection Imager (SMEI) and Interplanetary Scintillation (IPS) Web Database, and CCMC Models', SHINE-GEM Meeting, Midway, UT, U.S.A., June 2008 (oral presentation and poster).

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., and Clover, J.M., 2008, 'SMEI (Solar Mass Ejection Imager) (a Facility?)', NSF UARS-UAF Meeting, September 2008, Haystack Observatory, MA, USA (oral presentation).

Jackson, B.V., Bisi, M.M., Hick, P.P., Buffington, A., Clover, J.M., Webb, D.F., Tokumaru, M., and Manoharan, P.K., 2008, 'SMEI Remote Sensing and the 3D Reconstruction of Corotating Heliospheric Structures', AGU (American Geophysical Union) Fall Meeting, December 2008, San Francisco, CA, U.S.A. (poster).

Webb, D.F., Howard, T.A., Fry, C.D., Odstrcil, D., Jackson, B.V., and Bisi, M.M., 2008, 'Study of the Propagation of CMEs in the Inner Heliosphere Using SMEI and STEREO- SECCHI-HI Data', Spring AGU Joint Assembly, Ft. Lauderdale, FL, U.S.A., May 2008 (oral presentation).

2009:

Bisi, M.M., Jackson, B.V., Clover, J.M., Hick, P.P., Buffington, A., and Tokumaru, M., 2009, 'IPS 3D reconstructions and their comparison with STEREO and Wind spacecraft', STEREO SWG 19, Pasadena, CA, U.S.A., February 2009 (oral presentation).

Bisi, M.M., Jackson, B.V., Hick, P.P., Buffington, A., and Clover, J.M., 2009, '3D reconstructions of the inner heliosphere and their comparison with interplanetary spacecraft', JENAM/MIST/UKSP, University of Hertfordshire, England, April 2009 (poster).

Bisi, M.M., Jackson, B.V., Clover, J.M., Hick, P.P., Tokumaru, M., Manoharan, P.K., and Buffington, A., 2009, '3D reconstructions of the inner heliosphere using interplanetary scintillation observations and their comparison with in situ spacecraft measurements and white-light observations', STEREO-3/SOHO-22, Bournemouth, England, April/May 2009 (oral presentation).

Bisi, M.M., 2009, 'Proceedings of the 'Remote Sensing of the Inner Heliosphere – Aberystwyth Workshop' 05-08 May 2009 to appear in Solar Physics' - Remote Sensing of the Inner Heliosphere Workshop, Aberystwyth, Wales, May 2009 (oral presentation).

Bisi, M.M., 2009, 'Discussions and working on where to go with future remote-sensing observations and any obvious collaborations/work which are brought out as a result from these institutional summary talks plus recent comparative works with differing IPS arrays', Remote Sensing of the Inner Heliosphere Workshop, Aberystwyth, Wales, May 2009 (oral discussion session).

Bisi, M.M., 2009, 'The Interplanetary Scintillation (IPS) Data Format: a Brief Summary Following the Toyokawa IPS Workshop', Remote Sensing of the Inner Heliosphere Workshop, Aberystwyth, Wales, May 2009 (oral presentation).

Bisi, M.M., 2009, 'Discussion on where to go with white-light observations, proper calibration of the HIs, and possibilities of future white-light tomographic reconstructions with SMEI, HI, and other sources of remote-sensing white-light observations', Remote Sensing of the Inner Heliosphere Workshop, Aberystwyth, Wales, May 2009 (oral discussion session).

Bisi, M.M., Jackson, B.V., Hick, P.P., Clover, J.M., Tokumaru, M., Fujiki, K., Fallows, R.A., and Breen, A.R., 2009, 'Three-Dimensional Reconstructions of the Solar Wind: During Solar Minimum Conditions', AAS SPD, Boulder, CO, USA, June 2009 (oral presentation).

Bisi, M.M., Jackson, B.V., Clover, J.M., Tokumaru, M., and Fujiki, K., 2009, 'Large-Scale Heliospheric Structure during Solar-Minimum Conditions using a 3D Time-dependent

Reconstruction Solar-Wind Model and STELab IPS Observations', Solar Wind 12, St. Malo, France, June 2009 (poster).

Bisi, M.M., Jackson, B.V., Clover, J.M., Tokumaru, M., Fujiki, K., Breen, A.R., Fallows, R.A., and Buffington, A., 2009, 'The Large-Scale Structure of the Solar Wind during Solar Minimum Conditions Using Three-Dimensional Reconstructions of Interplanetary Scintillation Data', SHINE (Solar, Heliospheric & INterplanetary Environment) Workshop, Wolfville, NS, Canada, August 2009 (poster).

Bisi, M.M., Jackson, B.V., Clover, J.M., Hick, P.P., Buffington, A., and Tokumaru, M., 2009, '3D Reconstructions of the Whole Heliosphere Interval and Comparison with in-Ecliptic Solar Wind Measurements from STEREO, ACE and Wind Instrumentation', International Astronomical Union, Joint Discussion 16 (JD16) on the Whole Heliosphere Interval (WHI), Rio de Janeiro, Brazil, August 2009 (oral presentation).

Bisi, M.M., Jackson, B.V., Clover, J.M., Tokumaru, M., Buffington, A., Hick, P.P., and Fujiki, K., 2009, 'Coronal Mass Ejections and Large-Scale Solar Wind Structure in the Declining and Minimum Phase between Solar Cycles 23 and 24', International Living With a Star (ILWS) Workshop, Ubatuba – SP, Brazil, October 2009 (oral presentation).

Breen, A.R., Dorrian, G.D., Fallows, R.A., Morgan, H., Bisi, M.M., Davies, J.A., and Roulliard, A.P., 2009, 'Exploring the large-scale structure of the solar wind: recent advances from combined radio scintillation and white-light imager results', JENAM/MIST/UKSP, University of Hertfordshire, England, April 2009 (poster).

Breen, A.R., Dorrian, G.D., Fallows, R.A., Morgan, H., Bisi, M.M., Davies, J.A., and Roulliard, A.P., 2009, 'Exploring the large-scale structure of the solar wind: recent advances from combined radio scintillation and white-light imager results', STEREO-3/SOHO-22, Bournemouth, England, April/May 2009 (poster).

Breen, A.R., Fallows, R.A., and Bisi, M.M., 2009, 'Heliospheric physics with LOFAR', LOFAR Workshop, Potsdam, Germany, June 2009 (oral presentation).

Buffington, A., Hick, P.P., Jackson, B.V., Bisi, M.M., and Clover, J.M., 2009, 'Long-term removal/reduction of sidereal and zodiacal-light contributions to SMEI white-light sky maps' STEREO-3/SOHO-22, Bournemouth, England, April/May 2009 (poster).

Buffington, A., Jackson, B.V., Bisi, M.M., Clover, J.M., and Hick, P.P., 2009, 'Removal of background light from SMEI white-light all-sky maps, and an all-sky imager design suitable for future deep-space missions" - Remote Sensing of the Inner Heliosphere Workshop, Aberystwyth, Wales, May 2009 (oral presentation).

Buffington, A., Bach, K.G., Bach, B.W., Bach, E.K., Bisi, M.M., Hick, P.P., Jackson, B.V., and Klupar, P.D., 2009, 'Fabrication and Test of a Diamond-turned Mirror Suitable for a Spaceborne Photometric Heliospheric Imager', SPIE Optical Engineering + Applications 2009 meeting, San Diego, CA, U.S.A., August 2009 (oral presentation).

Clover, J.M., Bisi, M.M., Buffington, A., Jackson, B.V., and Hick, P.P., 2009, ‘Measurements of White-Light Images of Cometary Plasma as a Proxy for Solar Wind Speed’, Remote Sensing of the Inner Heliosphere Workshop, Aberystwyth, Wales, May 2009 (oral presentation).

Clover, J.M., Bisi, M.M., Buffington, A., Jackson, B.V., and Hick, P.P., 2009, ‘Measurements of White-Light Images of Comet Plasma Tails as a Proxy for Solar Wind Speed’, SHINE (Solar, Heliospheric & INterplanetary Environment) Workshop, Wolfville, NS, Canada, August 2009 (oral presentation and poster).

Dorrian, G.D., Breen, A.R., Davies, J.A., Roulliard, A.P., Bisi, M.M., Whittaker, I., and Fallows, R.A., 2009, ‘Simultaneous Heliospheric Imager and Interplanetary Scintillation observations of CMEs and CIRs’, STEREO SWG 19, Pasadena, CA, U.S.A., February 2009 (oral presentation).

Dorrian, G.D., Breen, A.B., Whittaker, I., Grande, M., Davies, J.A., Rouillard, A.P., Bisi, M.M., and Fallows, R.A., 2009, ‘Interacting Structures in the Solar Wind: IPS and STEREO HI Observations’, Solar Wind 12, St. Malo, France, June 2009 (oral presentation).

Fujiki, K., Ito, H., and Tokumaru, M., given by Bisi, M.M., 2009, ‘Solar Wind Forecast by using Interplanetary Scintillation Observations’, Remote Sensing of the Inner Heliosphere Workshop, Aberystwyth, Wales, May 2009 (oral presentation).

Gibson, S.E., Arge, C.N., Bisi, M.M., Clover, J.M., de Toma, G., Emery, B., Galvin, A., Gopalswamy, N., Gosling, J., Haber, D., Hick, P.P., Jackson, B.V., Kozyra, J.U., Leamon, R., Lei, J., Manoharan, P.K., McIntosh, P.S., McIntosh, S., Onsager, T., Petrie, G., Reinard, A., Plunkett, S., Qian, L., Riley, P., Soloman, S., Schroeder, P., Tokumaru, M., Thompson, B.J., Webb, D., ‘End-to-end observations and modeling of Whole Heliosphere Interval: Origins and impacts of high-speed streams’, International Astronomical Union, Joint Discussion 16 (JD16) on the Whole Heliosphere Interval (WHI), Rio de Janeiro, Brazil, August 2009 (poster).

Hick, P.P., Jackson, B.V., Bisi, M.M., Clover, J.M., and Buffington, A., 2009, ‘Faraday Rotation: Expected Possible Analyses from Polarized Radio Sources and Other Matters’, Remote Sensing of the Inner Heliosphere Workshop, Aberystwyth, Wales, May 2009 (oral presentation).

Jackson, B.V., Bisi, M.M., Hick, P.P., Buffington, A., Clover, J.M., and Webb, D.F., 2009, ‘SMEI-STEREO Comparisons’, STEREO SWG 19, Pasadena, CA, U.S.A., February 2009 (oral presentation).

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., and Clover, J.M., 2009, ‘SMEI direct and 3D-reconstruction sky maps and other higher-level data products and their comparison with SOHO and STEREO instrumentation’ STEREO-3/SOHO-22, Bournemouth, England, April/May 2009 (oral presentation).

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., and Clover, J.M., 2009, 'A Summary of UCSD Work Since the Toyokawa IPS Workshop', Remote Sensing of the Inner Heliosphere Workshop, Aberystwyth, Wales, May 2009 (oral presentation).

Jackson, B.V., Buffington, A., Bisi, M.M., and Clover, J.M., 'A Heliospheric All-Sky Imager', SPRSA – Small Payload Rideshare Workshop, NASA Ames Research Center, May 2009 (oral presentation not given as workshop time was poorly managed, and associated SMEX poster).

Jackson, B.V., Buffington, A., Hick, P.P., Bisi, M.M., and Clover, J.M., 2009, 'A Heliospheric Imager for Solar Orbiter – Lessons Learned from HELIOS, SMEI, and STEREO', 3rd Solar Orbiter Workshop, Sorrento, Italy, May 2009 (poster).

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., Clover, J.M., Tokumaru, M., and Fujiki, K., 2009, '3D-Reconstruction of Density Enhancements Behind Interplanetary Shocks from Solar Mass Ejection White-Light Observations', AAS SPD, Boulder, CO, USA, June 2009 (poster).

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., Clover, J.M., Tokumaru, M., and Fujiki, K., 2009, 'The Solar Mass Ejection Imager (SMEI) 3D-reconstruction of density enhancements behind interplanetary shocks', Solar Wind 12, St. Malo, France, June 2009 (poster).

Jackson, B.V., Bisi, M.M., Clover, J.M., Hick, P.P., and Buffington, A., 2009, 'The UCSD Solar Mass Ejection Imager (SMEI) and Interplanetary Scintillation (IPS) 3D Reconstructions and Databases now at the CCMC', SHINE (Solar, Heliospheric & INterplanetary Environment) Workshop, Wolfville, NS, Canada, August 2009 (oral presentation and poster).

Jackson, B.V., Bisi, M.M., Hick, P.P., Buffington, A., Clover, J.M., Webb, D.F., and Tokumaru, M., 2009, 'SMEI Remote Sensing and the 3D Reconstruction of Corotating Heliospheric Structures During WHI', International Astronomical Union, Joint Discussion 16 (JD16) on the Whole Heliosphere Interval (WHI), Rio de Janeiro, Brazil, August 2009 (oral presentation).

Jackson, B.V., Hick, P.P., Buffington, A., Bisi, M.M., Clover, J.M., and Tokumaru, M., 2009, 'Solar Mass Ejection Imager (SMEI) 3D-reconstructions of the inner heliosphere', 6th Asia-Oceania Geophysical Society General Assembly, Singapore, August 2009 (oral presentation).

Jackson, B.V., Bisi, M.M., Hick, P.P., Buffington, A., Clover, J.M., and Webb, D.F., 2009, 'SMEI and IPS remote sensing and 3D reconstruction of corotating heliospheric structures during solar minimum', SOHO-23, NE Harbor, Maine, USA, September 2009 (poster).

Jackson, B.V., Hick, P.P., A. Buffington, A., Bisi, M.M., Clover, J.M., Hamilton, S., Tokumaru, M., and Fujiki, K., 2009, 'The Solar Mass Ejection Imager (SMEI) 3D-reconstruction of density enhancements behind interplanetary shocks', International Living With a Star (ILWS) Workshop, Ubatuba – SP, Brazil, October 2009 (oral presentation).

Tokumaru, M., Kojima, M., Fujiki, K., Itoh, H., and Iju, T., given by M.M. Bisi and P.K. Manoharan, 2009, 'Upgrade of STEL Multi-Station Interplanetary Scintillation System and

Recent Observations of the Solar Wind’, Remote Sensing of the Inner Heliosphere Workshop, Aberystwyth, Wales, May 2009 (oral presentation).

Webb, D.F., Galvin, A., Gopalswamy, N., Haber, H., McIntosh, P., Jackson, B.V., Bisi, M.M., and Plunkett, S.P., 2009, ‘Tracking CMEs from the Sun into the Heliosphere During the WHI Period’, SOHO-23, NE Harbor, Maine, USA, September 2009 (poster).

Interactions/Transactions: (see body of text, references and article list above)

New Discoveries: none

Honors/Awards:

J. Geophys. Res. editors choice awards:

Bisi, M.M., Jackson, B.V., Hick, P.P., Buffington, A., Odstrcil, D., and Clover, J.M., 2008, ‘3D Reconstructions of the Early-November 2004 CDAW Geomagnetic Storms: Analyses of STELab IPS speed and SMEI density data’, (CDAW) *J. Geophys. Res*. Special Edition - Geomagnetic Storms of Solar Cycle 23, 113, A00A11, doi:10.1029/2008JA013222.

Jackson, B.V., Bisi, M.M., Hick, P.P., Buffington, A., Clover, J.M., and Sun, W., 2008, ‘Solar Mass Ejection Imager (SMEI) 3D Reconstruction of the 27-28 May 2003 CME Sequence’, (CDAW) *J. Geophys. Res*. – Special Edition - Geomagnetic Storms of Solar Cycle 23, 113, A00A15, doi:10.1029/2008JA013224.

Journal *Icarus* front page:

Buffington, A., Bisi, M.M., Clover, J.M., Hick, P.P., Jackson, B.V., Kuchar, T.A., and Price, S.D., 2009, ‘Measurements of the Gegenschein brightness from the Solar Mass Ejection Imager (SMEI)’, *Icarus*, 203, 124, doi:10.1016/j.icarus.2009.04.007.